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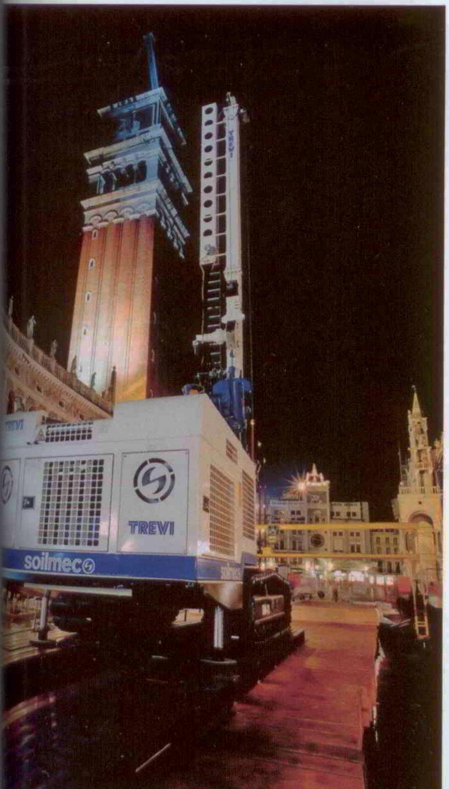
Taming Noise, Vibrations At West Toronto Diamond Rail Grade Separation Project

Deep Soil Mixing Helps Restore Venice's San Marco Bell Tower



Soil Mixing is underway in Venice's historic center

The bell tower in Venice, Italy's, Piazza San Marco dating back to the 12th century, is currently being strengthened to improve its foundations. The construction of the original tower started at the beginning of the 10th century and lasted to the beginning of the 12th century. On July 14, 1902, at 9:47 am the tower collapsed and 14,000 tons of bricks and debris dropped ruinously over the square, causing the collapse of the northeast foundations from the original 224 m^2 (2,411 sq ft) to 410 m^2 (4,413 sq ft). The reconstruction began in 1903 and was completed in 1908. The new masonry was locked together to the original, inserting new stone blocks to the old ones.

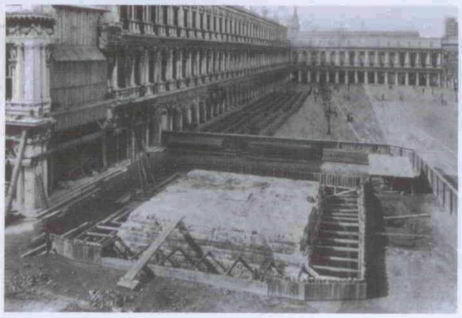
However, the designers who oversaw the repair extended the foundation area and not the height; this later caused cracks on all the four sides of the new foundation. These cracks have been monitored from the early 1950s, and show constant increase with time. In the 1990s, authorities decided to undertake a new intervention.

After a thorough investigation, the designers (Studio Macchi and Studio Geotecnico) stated that no foundation improvements were needed; only an intervention to stop the progression of the cracks. The Ministry of Infrastructure and Transport — Venice Water Authority, through the concessionary Consorzio Venezia Nuova, drew up the plans for this restoration. Trevi S.p.A (from Trevi Group, Italy) has been involved in the technological design and execution of all the specialized work.

Soil Profile and Geotechnical Framework

The intervention work is underway in extremely sensitive geotechnical conditions, characterized by the presence of soft and fine lagoon sediments, with extensive historic fill, especially in central Venice. The typical soil profile in the area of the Piazza San Marco was identified using boreholes and CPTU tests carried out in four stages, from 1993 to 2006. The soil profile is as follows:

- From Piazza San Marco pavement level at +0.90 m (2.95 ft) mean sea level (MSL) to approximately 5.0 m (16.4 ft), fill is made up of sandy-clayey silts (locally medium to fine sand with silt). Presence of masonry debris, trachyte blocs, wooden piles and unreinforced concrete.
- Below fill to 6.0 – 7.0 m (20 – 23 ft) depth from ground level (GL), a layer of soft sandy clayey silt and/or silty clay with organic debris and peat.
- From 6.0 – 7.0 m (20 – 23 ft) depth from GL to 10.0 m (33 ft), medium to fine sand.
- Below 10.0 m (33 ft) deep, an alternating silty clay, clayey silts and silty sands were found. A typical CPTU profile around the bell tower is shown in Figure 1.



The old footings of the bell tower during the 1903 reconstruction

Titanium Rebar

The intervention consists of installing two levels of prestressed titanium rebars into the foundation block, to increase the overall flexural stiffness of the foundation. Titanium was selected for its high resistance to corrosion, even in extremely aggressive environments such as saltwater. The first level was to be placed at about 40 cm (16 in) below the square floor and the second level about 2.30 m (7.5 ft) deeper, below the water table and surrounded by an existing block of massive concrete. It was necessary to drill through the concrete to insert the bars along the four sides of the foundation in the correct position. The designers selected deep cement mixing (DCM) columns, reinforced with steel pipes to provide watertightness, lateral support, as well as bottom resistance to uplift for the seven pits ("chambers"). The pits, in turn, were used to install the titanium bars. The chambers are mostly below the water table, and will remain accessible after the project is completed, to allow for monitoring of the titanium bars and to allow future interventions, if necessary.

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Titanium rods were drilled through the foundation stone blocs and anchored at the foundation's corners by titanium plates, being initially prestressed to 250 kN (28 tons) each. Depending on the foundation's structural responses, stresses in the titanium rods could be adjusted over a few years.

Corner chambers have 10 –15 m^2 (107 – 161 sq ft) area, with different shapes according to surface constraints. Lateral walls of the chambers are formed with two or three rows of secant DCM columns having a diameter of 0.40 or 0.50 m (16 or 20 in), 8 – 9 m (26 – 30 ft) deep. Average compressive strength of the treated soil is in the order of 0.5 MPa (72 psi).

From a geotechnical point of view, the main project issues were:

- Watertightness of the chambers during excavation, to avoid any losses of fines due to water inflow
- Stability of lateral walls of the chambers during excavation
- Resistance to uplift of the chambers in temporary conditions taking into account the periodic "high water"
- Control and limitation of total and differential settlements of existing foundations (bell tower and Procuratie Nuove) to very small values, as compared to recorded seasonal movement due to tide, temperature, wind, etc.
- Control and limitation of vibrations induced by construction

The dead weight of the reinforced concrete chamber walls and the chamber cover guarantee resistance to uplift at the corner chambers after the project is completed. Stability in temporary construction conditions, after chamber excavation and during the reinforced concrete walls construction, was guaranteed by the dead weight of the treated soil (taken as a massive block), and, possibly, by side friction against the alignment of the DCM columns.

The strength of the treated soil, in terms of unconfined compressive strength, was considered less critical than the density issue, since expected stresses in treated soil columns during chambers excavation are relatively low (<2.0 MPa or 290 psi).

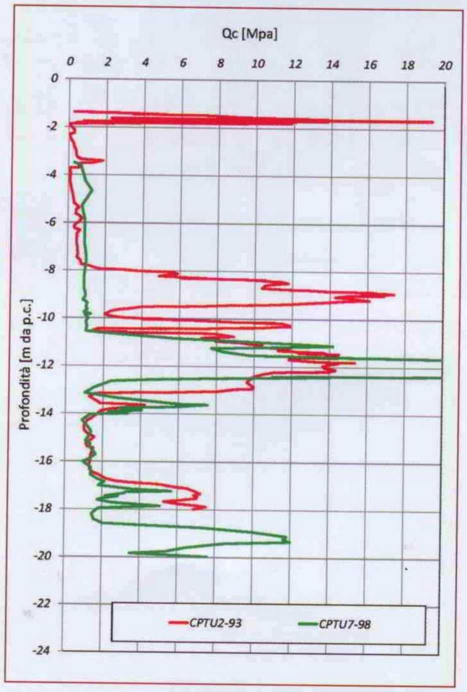


Figure 1. Typical profiles of CPTU around the San Marco Bell Tower

Worksite in the Heart of Venice

The jobsite is in the very heart of Venice, in the Piazza San Marco in front of the Basilica, packed every day by thousands of tourists. The authorities required the job footprint to be minimized, to reduce disturbance to the normal life of the city and of the tourists.

Trevi selected a small/medium size drilling rig (unusual for DCM columns) that could produce the small diameter columns needed to minimize disturbance at the historic site. Transporting the rig (SM 21 Soilmec–Trevi Group) from the San Marco Basin to the bell tower required a special platform to distribute the weight of the rig (nearly 220 kN or 25 tons) and fulfill the municipal regulation that limits the maximum allowable pressure on the square paving "masegni" (trachyte grey stones) to 3 kPa (0.45 psi). The workers built the platform using a 150 mm (6 in) layer of sand and a layer of neoprene, covered with wooden beams, over which steel I-beams were placed, blocked laterally with retainers anchored to the wooden beams. The 160 m (175 yd) route was covered in four stages of 40 m (43.7 yd) each. After each stage during the night, workers disassembled the platform, then reassembled it in front of the machine. The entire stretch took less than a week to arrive at its destination.

The other major concern was the effect on the existing monuments, in particular the bell tower and the nearby Procuratie Nuove with the Marciana Library, in terms of induced settlements and rotations.

The two monuments have different foundation systems (Figure 2):

- The bell tower is founded on driven wooden piles, penetrating the sand layers below 6.0 – 7.0 m (20 – 23 ft) deep; the original foundation was reinforced with 300 additional piles during the 1912 reconstruction.
- The Procuratie Nuove sits on shallow foundations, with an expected depth slightly smaller than the design excavation level of the corner chamber on the south side of the bell tower. Along this side the overall strength of the intervention was improved by incorporating 50 cm (20 in) diameter DCM columns and increased steel pipe reinforcement.

Preliminary laboratory tests determined the best cement content to obtain the strength required by the designer, and to assess the achievable density of the mixed soil. The preliminary noise and vibration tests suggested that the expected vibration level during DCM column construction was negligible and would not appreciably disturb residents and tourists. Full-scale tests measured the vibrations and the noise generated by the rig during the column installation, and confirmed those results.

Test results confirmed the possibility of achieving the required minimum compressive strength of 0.35 MPa (50 psi) at 28 days curing and the minimum unit weight of 18 kN/m^3 (1.52 tons/cu yd).

The main work on the Piazza San Marco started in early August 2009. Due to the possible presence of underground obstacles, the columns were drilled to the full depth using the minimum quantity of water. The cement slurry was added during retrieval at fixed speed. As the lower half of the columns is in fine sand and the upper half in cohesive, soft, organic material, the tool was rapidly moved twice up and down to enhance the homogenization of the cemented fresh soil column. Special mixing tools have been developed to cope with the obstacles.

During the work, requirements called for adjusting the thickness of the bottom plugs for some of the chambers, due to the unexpectedly low unit weight of treated soil detected from routine control tests, the reason being the large amount of wood chips from buried wood abandoned after historical works.

The columns bordering the chamber walls are reinforced with 88.9 mm (3.5 in) diameter steel pipe installed through the column's axis, after curing and re-drilling.

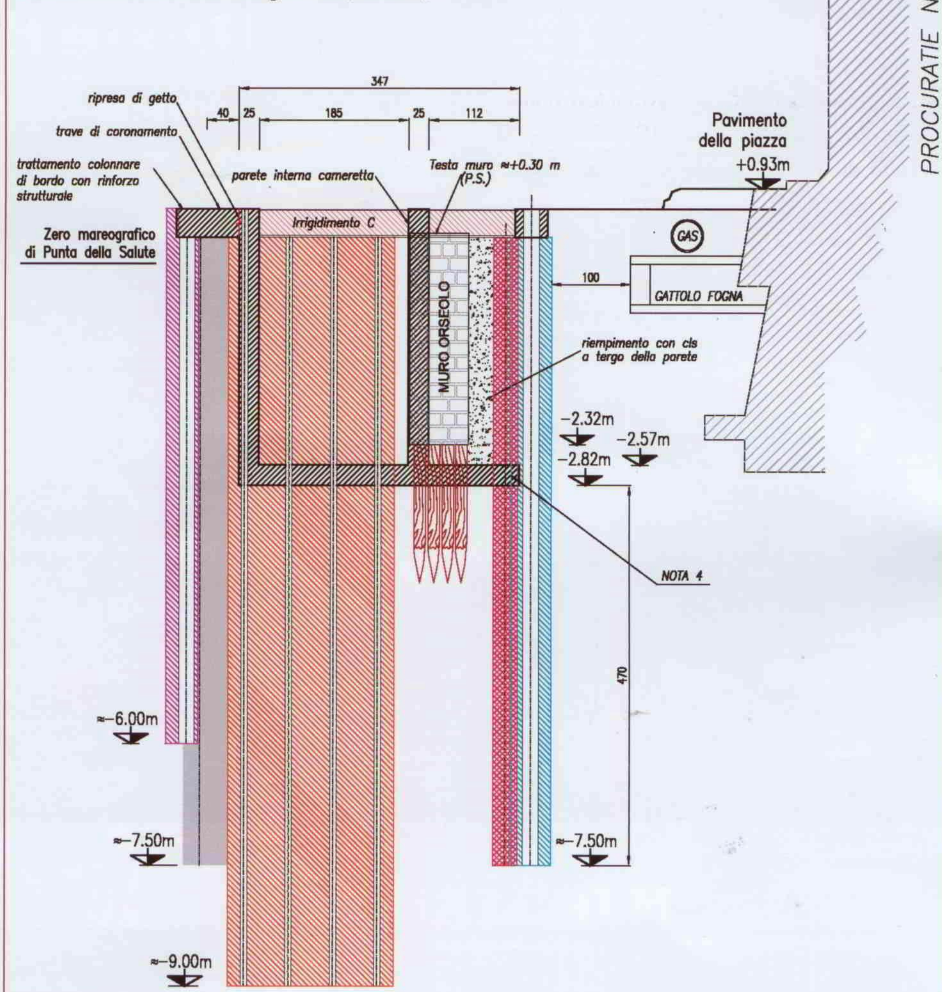
The spoil generated during the DCM installation was collected and pumped to a filter press dewatering plant, which reduces its volume. The dried spoil is then transported by small cart to the quay, and boarded on pontoons to the final disposal area.

The work progress was slowed through periodic flooding. The pavement of Piazza San Marco is at around +0.9 m above mean sea level, and, under the terms of the contract, works were halted whenever tides rose to +1.0 m elevation, for "acqua alta" or high tide.

The excavation of the chambers, begun in August 2010, showed the general good quality of the job done with very limited water inflow and very small movements of the monuments (bell tower and Procuratie Nuove), as shown by the monitoring system. The monitoring system data and, in particular, the 30 m (98 ft) long-base pendulum installed inside the bell tower shows that the movements of the bell tower during the intervention changed only few millimeters with respect to the usual seasonal variations.

The restoration is scheduled to be completed by the end of 2012.

Figure 2. Cross section of SW chamber showing the position of foundations of Procuratie Nuove (right) and of the buried Orseolo stone masonry wall (center)



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Watertight work pit for deep soil mixing in Venice

The job site with "acqua alta" (high tide)